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SOME DYNAMIC ASPECTS OF EXTENDED POLLUTION EPISODES

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Abstract—A boundary layer trajectory model was used to compute the residence time of air parcels within transient high-pressure systems of Canadian origin traversing the eastern Ohio River Valley. A strong correlation was noted among the presence of a transient anticyclone, elevated pollution levels, deteriorating horizontal visibility, and the length of time an air parcel entering the boundary layer of the high-pressure system had been entrained.

INTRODUCTION

A large body of research over the past decade has been devoted to the elevated pollution episode. One phase of this work has revolved around the investigation of nonurban ozone (O_3) buildups, particularly as they relate to high-pressure systems and their movement (Bach *et al.*, 1976; Vukovich *et al.*, 1977; Decker *et al.*, 1976; EPA Report, 1974; EPA Report, 1975; Sampson and Ragland, 1977; Wolff *et al.*, 1976; 1981; Spicer *et al.*, 1979.) This extended research effort has suggested the following major conclusions:

(1) Atmospheric conditions in a high-pressure system lend themselves to the synthesis of ozone, providing sufficient ozone precursors have been injected into the system.

(2) High ozone during the summer months is associated with high-pressure systems.

(3) The concentration of ozone within an air parcel in a high-pressure system correlates with the residence time of the air parcel within the system.

(4) Air parcels on the "back side" of a moving high-pressure system have had the longest residence time and contain the highest ozone concentrations in the system.

(5) Maximum residence times within a moving high-pressure system vary inversely with the speed at which the system is moving.

(6) Maximum ozone concentrations in transient high-pressure systems on the continental United States are higher the farther east (where the population density is greatest) the system moves, suggesting the importance of anthropogenic sources of ozone precursor material to the synthesis of ozone within the high.

There has been limited evidence that pollutants other than ozone reach high levels in high-pressure systems (Husar *et al.*, 1976; Vukovich, 1979). Restricted horizontal visibility due to lithometeor obstructions to vision (smoke and/or haze, and other dry atmospheric suspensoids) has been suggested as a possible indicator and method of monitoring the progress of a pollution episode. This paper presents a preliminary evaluation of the dynamic meteorological conditions in a restricted visibility state utilizing the same basic research techniques that were developed during the course of numerous summer ozone field programs. Comparisons have been made among the various data components to determine the relative coincidence of peaks in air pollution levels and minimum visibility readings in the area of the Ohio River Valley. Then the dynamics of several transient anticyclones are examined to see just how well system residence times compare with *in situ* visibility and pollution concentration data.

THE STUDY AREA AND DATA BASE

Several surface analyses were performed over a macroscale study area centered along the Ohio River Valley and including most of the northeast and north central United States from approx. 36–46° north and from 73 to 92° west. This region was selected because, in the summer of 1974, a number of transient anticyclones traversed the area during periods when two major air pollution monitoring programs were operating. The Summer Ozone Study field network stations of the Research Triangle Institute (RTI) were operating at Wilmington, McConnellsville and Wooster, OH; DuBois, PA and McHenry, MD. At the same time, the Electric Power Research Institute (EPRI) stations in the Sulfate Regional Experiment (SURE) network were taking 24-h average measurements of sulfate (SO_4), sulfur dioxide (SO_2), and total suspended particulate (TSP). The SURE stations were located at Rockport, Madison, and Lawrenceburg, IN; Collins, IL; Huntington and Wheeling, WV; Scranton, PA and Albany, NY.

Weather data for the period including visibility,

present weather, station pressure, dry bulb and dew point temperatures, surface analyses, and anticyclone movement were obtained from U.S. Department of Commerce publications such as *Daily Weather Maps*; *Climatological Data, National Summary*; and *Local Climatological Data* summaries for 61 National Weather Service (NWS) first-order stations over an 18-State area.

In addition to the primary study area, a 500 × 500 km square mesoscale study area centered around Columbus, OH, was used for certain detailed analyses including the effects of system residence time upon pollution levels and horizontal visibility.

PEAKS IN STATION PRESSURE, AIR POLLUTION AND RESTRICTED VISIBILITY

A simple test was devised for comparing the relative coincidence of occurrence of maximum values of station pressure, various pollutant concentrations and restricted visibility. The data for this test were taken from the mesoscale study area previously described and were compiled as follows:

(1) Station pressure—the area-averaged, daily average station pressure (inches of mercury) computed from the following cluster of NWS stations in northern OH: Akron, Cleveland, Columbus, and Youngstown;

(2) Restricted visibility—the area-averaged, 1700 EDT visibility reported at the following cluster of NWS stations: Akron, Cleveland, Mansfield and Youngstown. The 1700 EDT visibility was used in order to remove the effects of morning fog.

(3) Ozone—the area-averaged, 8-h average (1200–2000 EDT) ozone concentration ($\mu g\,m^{-3}$) computed from the following RTI ozone monitoring sites in OH: Wilmington, McConnellsville and Wooster.

(4) Sulfate, sulfur dioxide and total suspended particulate—the area-averaged, 24-h average concentration ($\mu g\,m^{-3}$) computed from the following EPRI SURE stations: Lawrenceburg, IN; Huntington and Wheeling, WV.

For the study period, a quasi-Julian day numbering system was adapted beginning with 16 June 1974 (day 1) and running until 31 August 1974 (day 77). The quasi-Julian day when peaks were reached in each of the above listed parameters are given in Table 1. From these data, station pressure seems to peak generally before the other parameters, particularly before restricted visibility. This follows the expected scenario: a high-pressure system moves through the area; the pressure rises and peaks as the system center passes the monitoring station; during this time, pollution levels rise and visibility deteriorates with peaks being reached on the "back side" of the high.

Table 1. The quasi-Julian day various parameters reached peaks (16 June = day 1)

Station pressure	SO_2	TSP	Ozone	Sulfate	Restricted visibility
4	7	5	5	5	5
18	18	18	18	18	18
22	24	24	25	24	24
26	29	28	29	29	30
32	31	33	33	33	33
35	37	35	37	38	38
40	41	42	41	42	42
47	–	47	48	47	48
53	52	53	53	53	53
56	55	56	56	56	56
61	61	61	61	61	62
66	66	66	66	66	67
67	69	69	70	69	69
71	72	72	73	72	73

In order to determine which of these parameters most closely follows the trend in restricted visibility, the data in Table 1 are used to compare the date of occurrence of maximum restricted visibility relative to the date of occurrence of peaks in the other parameters (Table 2). These 14 cases suggest that maximum restricted visibility correlates best with peaks in SO_4, O_3 and TSP. As would be expected, the primary pollutant SO_2 appears to reach a maximum concentration in advance of the secondary pollutants; and then concentrations taper off as the SO_2 breaks down in the processes that yield the secondary pollutants. This contrasts with the results of Vukovich (1979), which suggest that the SO_2, SO_4 and TSP peaks occur simultaneously. With only three exceptions, minimum visibility was reached at the same time or after each of the other selected parameters peaked.

Table 2. Comparison of the date maximum restricted visibility occurred with the date of occurrence of peaks in sulfate, ozone, total suspended particulate, sulfur dioxide and station pressure

	Number of times maximum restricted visibility occurred						
Peaks in	2 days before	1 day before	Same day	1 day after	2 days after	3 days after	4 days after
Sulfate			9	5			
Ozone		2	7	5			
TSP			8	4	1	1	
SO_2	1		3	8	1		
Pressure			3	5	4	1	1

FOUR CASE STUDIES

In order to examine the relationships of visibility to air pollution in more detail, the following case study periods were defined:

9–15 July 1974	(days 24–30)
15–19 July 1974	(days 30–34)
19–23 July 1974	(days 34–38)
4–8 August 1974	(days 50–54).

Each case study covers a period between major frontal passages when a transient anticyclone of Canadian origin traversed the Ohio River Valley including the 500 × 500 km mesoscale study area. It has been found that west to east moving Canadian high-pressure systems remain relatively free of pollution buildups until they penetrate the industrialized north central United States (Bach *et al.*, 1976; Vukovich *et al.*, 1977). In every case, the center of the anticyclone passed to the north of Columbus, OH; three times within 200 km and once within 400 km.

As suggested earlier, as long as an air parcel remains in the domain of a moving high-pressure system, potential exists to develop higher concentrations of certain pollutants. This is particularly true of secondary pollutants such as ozone and sulfate. Figure 1 shows the residence time of air parcels within a circular symmetric anticyclone relative to the speed at which the system is moving. These residence time representations evolved from a boundary layer trajectory model (Vukovich *et al.*, 1977). This same model was used to calculate the residence time isopleths within the 500 × 500 km study area for each day of each case study period. There follows a discussion of the results of this modeling effort and the general meteorological conditions for each case study.

9–15 *July case study (day* 24–30)

A rather intense anticyclone developed on 9 July (day 24) to the northwest of Hudson Bay and began immediately moving to the south. An idealized representation of the system's location and direction of movement each day at 1700 EDT is given in Fig. 2. For simplification, the anticyclone is represented by a circle with a 1000-km radius. System speed and approximate central pressure are also indicated.

On day 29, the high-pressure system had stalled and was beginning to exhibit the first signs of anticyclolysis. The approximate position of the system on day 29 is indicated by the dashed circle centered in the extreme southeast corner of the Columbus study area. The system had totally dissipated by the following morning.

Figure 3 shows the 500 × 500 km study area centered on Columbus, OH. The isopleths indicate the

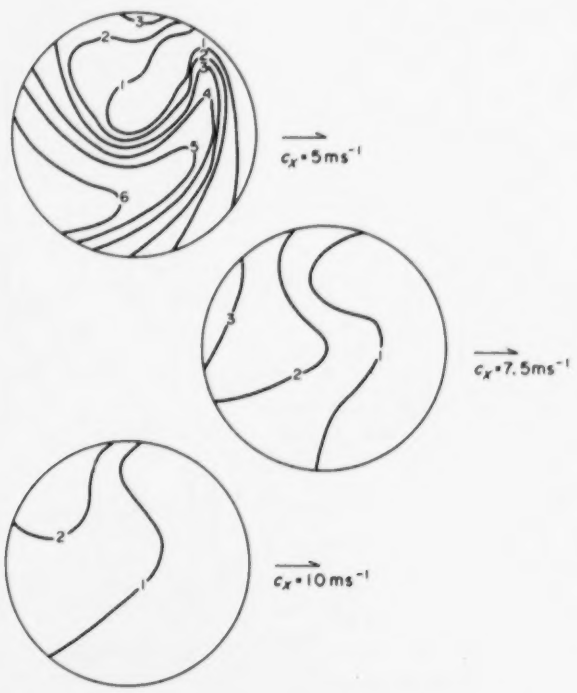

Fig. 1. The number of days air parcels in high pressure systems have spent (residence time) within the system vs the speed of the system, for a circular symmetric high pressure system with a radius of 1000 km.

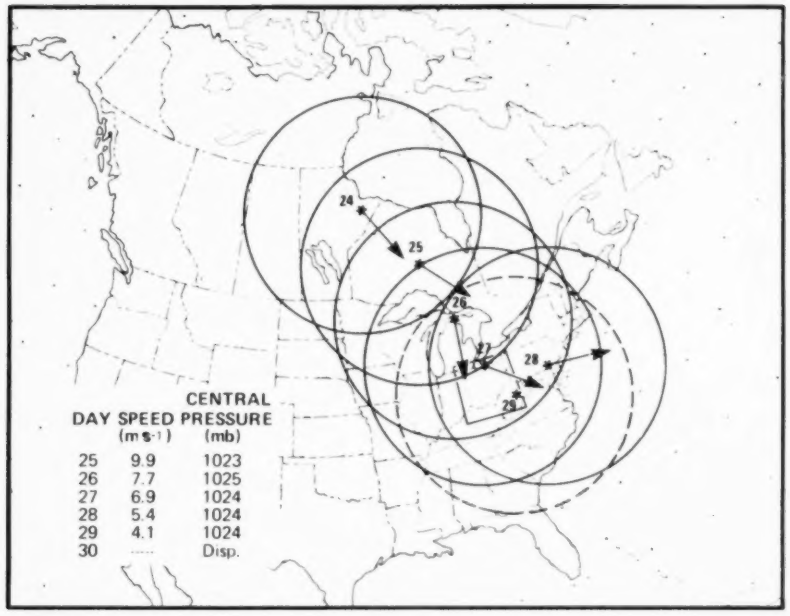

Fig. 2. Location and speed of movement at 1700 EDT each day for the 9–15 July case study. Also tabulated are 24 h average speed for the system and central pressure at 1700 EDT.

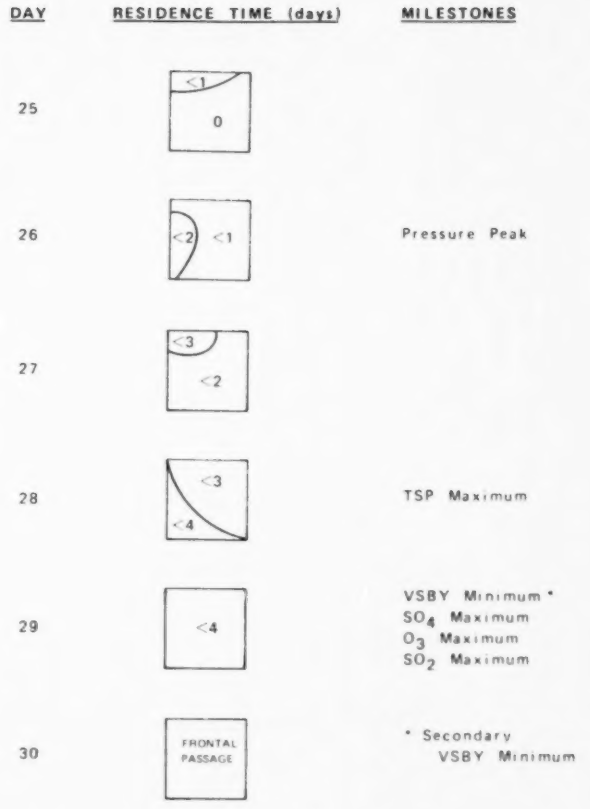

Fig. 3. Residence time (days) for each day of the 9–15 July case study in the 500 × 500 km Columbus study area.

residence time of air in the high-pressure system. Pollutant and meteorological milestones are noted. As the high-pressure system advanced, it slowed steadily, the center traversing the northern portion of the study area on day 27 (Fig. 2). On days 28 and 29, the air over the study area was on the "back side" of the system in the region of longest residence times (Fig. 3). The total suspended particulate concentration peaked out on day 28, with visibility and each of the other pollutants following suit on day 29 (Fig. 4).

On day 30, a weak cold front traversed the study area. The frontal zone showed little temperature variation but could be identified by an elevated dew point temperature and a 180° wind shift across the frontal zone. However, surface winds remained relatively light both behind and ahead of the front. As the front passed, the pollutant concentrations decreased. The visibility increased, except in an isolated region around Lake Erie extending south into West Virginia where smoke and haze continued to restrict visibility after the front had passed and well into the evening of day 30 before clearing. Why this anomaly occurred is not readily apparent from the available data.

15–19 *July case study (day 30–34)*

On 15 July (day 30), a ridge of high pressure developed over the north central United States and central Canada with its center northwest of Lake Superior. Figure 5 documents the progress of this large anticyclone, the center of which traversed the northern portion of the Columbus study area on the evening of day 31, picking up speed as it progressed. By the afternoon of day 33, the center was off the coast of Virginia. Although this idealized representation indicates the system had passed out of the Columbus area, the actual synoptic picture shows the system to be considerably larger with the study area still on the "back side" of the high. Figure 6 shows the residence time modeling analysis.

Of the four case studies, this 15–19 July anticyclone best exhibits the relationships suggested by the research in the previous section about visibility deterioration, anticyclone movement and system residence time. The reactive primary pollutant, sulfur dioxide, peaks early (day 31), followed the next day by the pressure peak as the anticyclone center traverses the study area. On day 33, the study area is on the "back side" of the high where air has reached maximum residence time within the system. On this day, visibility reached a minimum and the sulfates, total suspended particulate, and the secondary pollutant ozone, which is normally associated with photochemical smog, reached a maximum. Figure 7 shows the pattern of restricted visibility on day 33 on the "back side" of the

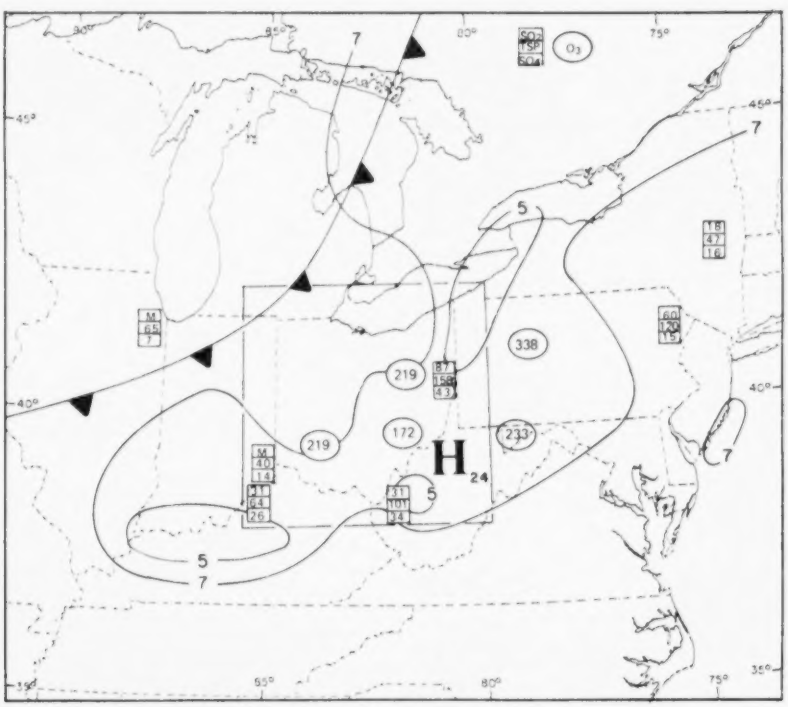

Fig. 4. 14 July (day 29) surface weather analysis showing visibility isopleths (miles) and the location of pressure centers and fronts. Also shown are 8-h average ozone values ($\mu g\,m^{-3}$) from the RTI network and 24-h average values for SO_2, TSP and SO_4 ($\mu g\,m^{-3}$) from the EPRI SURE network.

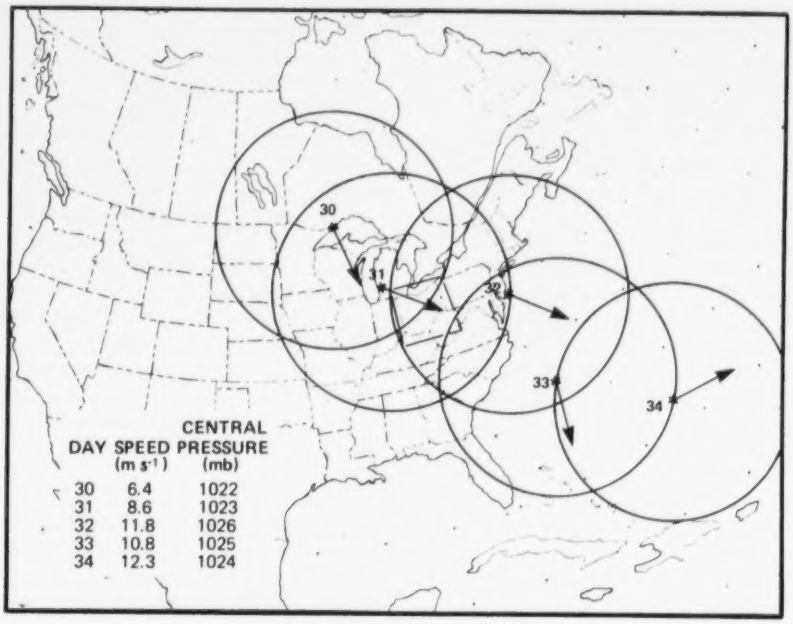

Fig. 5. Location and speed of movement at 1700 EDT each day for the 15–19 July case study. Also tabulated are 24 h average speed for the system and central pressure at 1700 EDT.

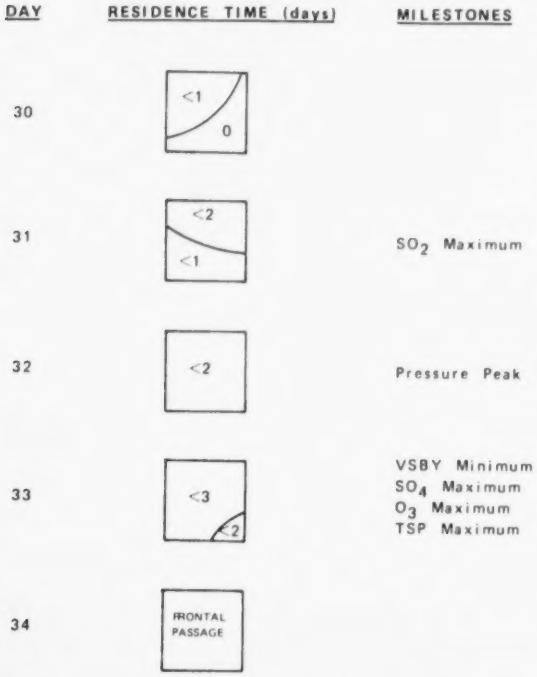

Fig. 6. Residence time (days) for each day of the 15–19 July case study in the 500 × 5-0 km Columbus study area.

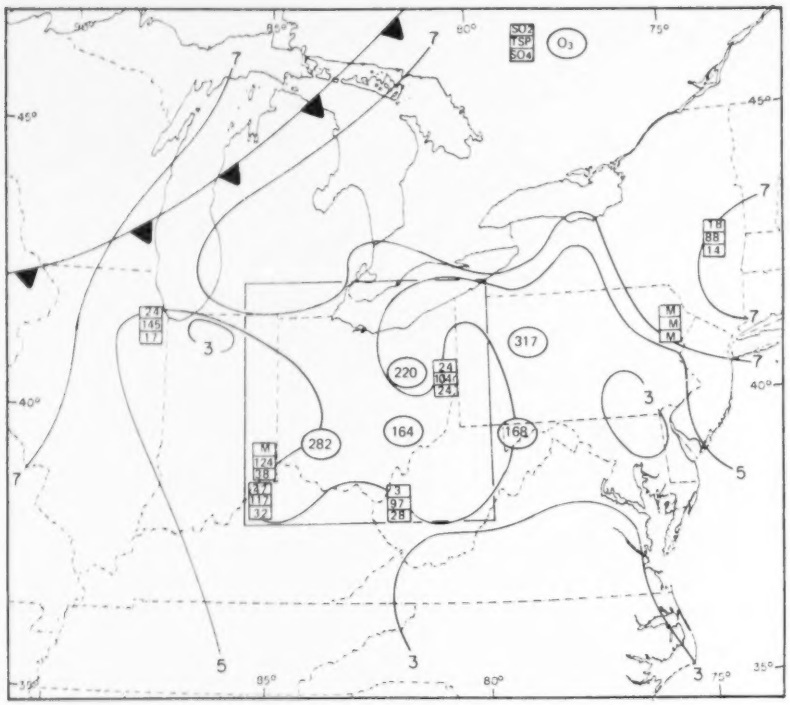

Fig. 7. 18 July (day 33) surface weather analysis showing visibility isopleths (miles) and the location of pressure centers and fronts. Also shown are 8-h average ozone values ($\mu g\,m^{-3}$) from the RTI network and 24-h average values for SO_2, TSP and SO_4 ($\mu g\,m^{-3}$) from the EPRI SURE network.

high. By day 34, the strong cold front shown in Fig. 7 had moved through the study area. The passage of this front, which was accompanied by rain showers and a pronounced wind shift, resulted in a dramatic reduction in air pollution levels and a corresponding increase in visibility.

19–23 *July case study* (*day* 34–38)

An anticyclone formed in the Beaufort Sea off the north shore of Alaska on 13 July. It then took 6 days to make its way southeastward across Canada, entering our study area (Fig. 8) on 19 July (day 34). At this point, partially blocked by a low off Nova Scotia, the high slowed and turned eastward, the center passing just north of the study area. Upon reaching the New England coast, the anticyclone again accelerated and continued up the coastline finally dissipating south of Labrador.

The residence time modeling analysis (Fig. 9) exhibits some rather interesting milestones. Although total suspended particulate peaked early (day 35), TSP levels remained near that peak through day 38. This episode did not terminate due to a frontal passage, but rather due to anticyclolysis on day 38. On day 37, the "back side" of the high was still quite well defined. Both the fairly reactive pollutants, ozone and sulfur dioxide, reached peaks. As dissipation set in on day 38, the system became disorganized with pressure dropping rapidly in the study area and some rain shower activity noted. Ozone and sulfur dioxide concentrations decreased sharply while sulfate reached a peak. Visibility dropped again significantly, and the sulfates increased on day 38. With no cleansing frontal passage, the pollutants appear to have remained in the area. Ozone concentrations dropped because the stable, high-insolation conditions conducive to O_3 synthesis no longer existed. SO_2 probably continued to react to form sulfate which combined with the increased atmospheric water vapor to further reduce visibility on day 38.

4–8 *August case study* (*day* 50–54)

This broad anticyclone formed just south of Victoria Island the evening of 31 July moving south and southeast until it was centered over northern Nebraska the morning of 4 August (day 50). It then turned 90 degrees and headed almost due east, dissipating off the New England coast on day 54 (Fig. 10). The residence time analysis is shown in Fig. 11. The sulfur dioxide peaked on day 52, and the other parameters on day 53 (Fig. 12).

SUMMARY AND CONCLUSIONS

Several idealized air parcel trajectories within a moving high pressure system are illustrated in Fig. 13.

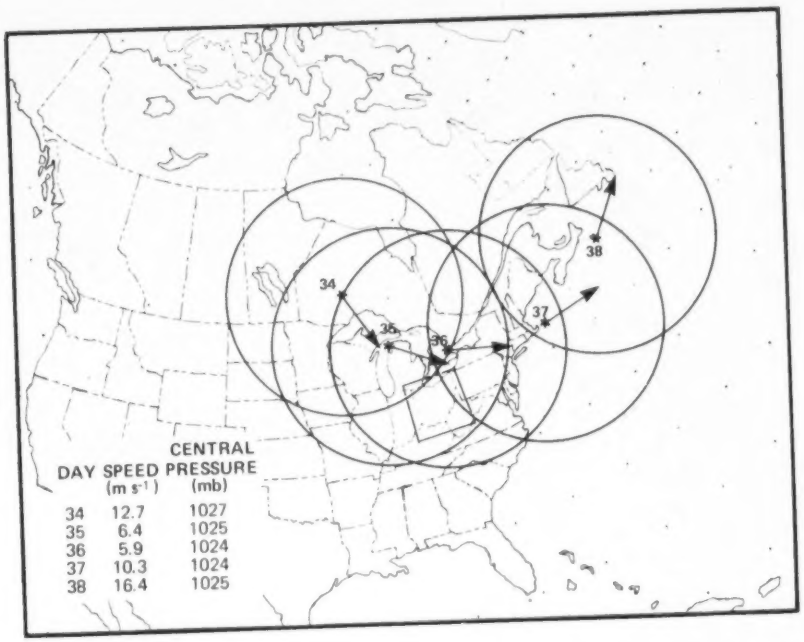

Fig. 8. Location and speed of movement at 1700 EDT each day for the 19–23 July case study. Also tabulated are 24 h average speed for the system and central pressure at 1700 EDT.

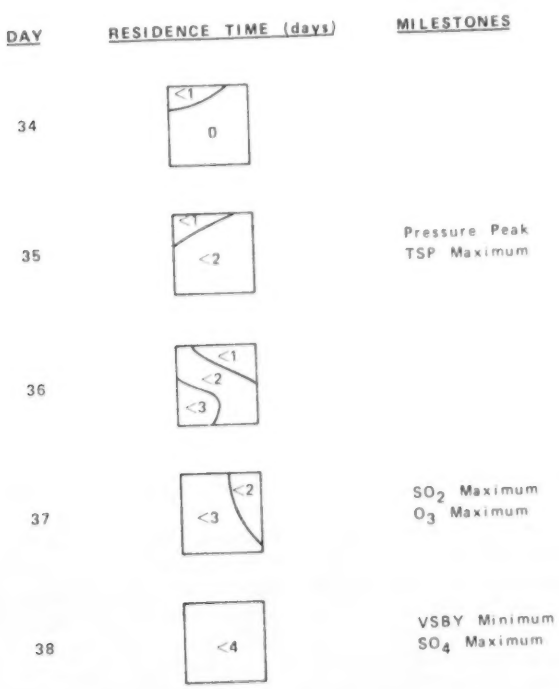

Fig. 9. Residence time (days) for each day of the 19–23 July case study in the 500 × 500 km Columbus study area.

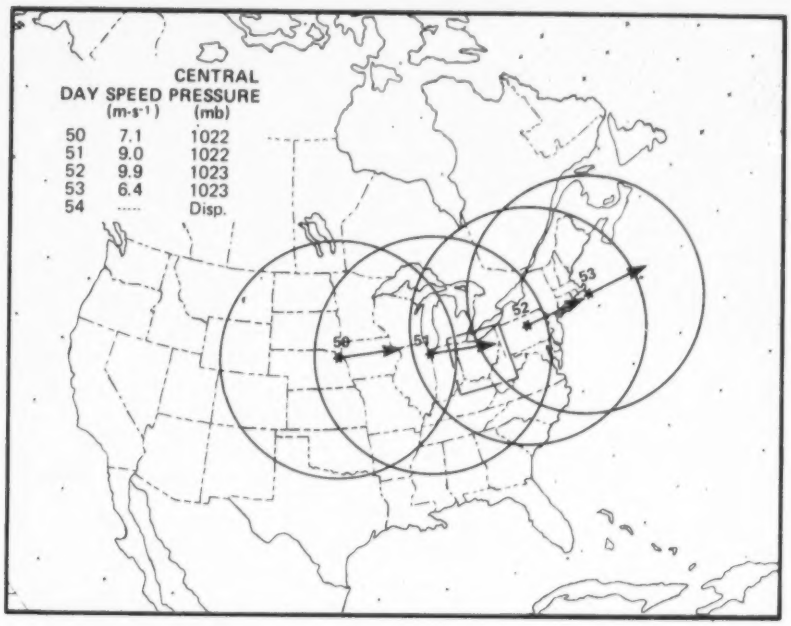

Fig. 10. Location and speed of movement at 1700 EDT each day for the 4–8 August case study. Also tabulated are 24 h average speed for the system and central pressure at 1700 EDT.

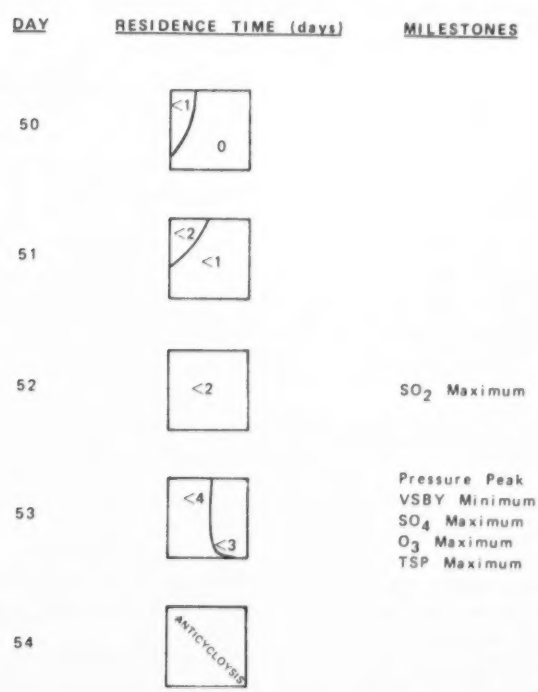

Fig. 11. Residence time (days) for each day of the 4–8 August case study in the 500 × 500 km Columbus study area.

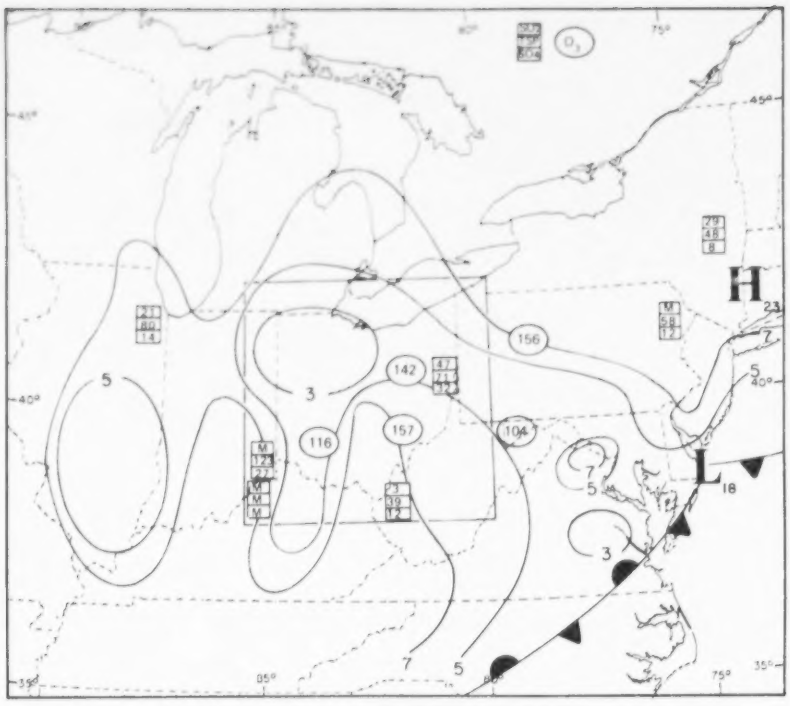

Fig. 12. 7 August (day 53) surface weather analysis showing visibility isopleths (miles) and the location of pressure centers and fronts. Also shown are 8-h average ozone values ($\mu g\,m^{-3}$) from the RTI network and 24-h average values for SO_2, TSP and SO_4 ($\mu g\,m^{-3}$) from the EPRI SURE network.

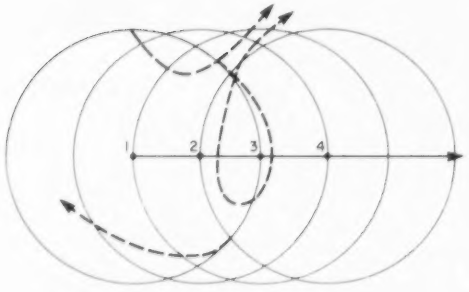

Fig. 13. Three idealized trajectories of air parcels in the boundary layer of a moving high pressure system.

With the system at position 1, parcels at the northern and southeastern boundary quickly lose anticyclonic curvature and pass out of the system. Typically, parcels entering from the northeast quadrant are subject to lengthy residence times within the high pressure system (Vukovich *et al.*, 1977). In this case, boundary layer dynamics force anticyclonic curvature of parcel trajectory so extreme as to result in actual looping and the possibility of a parcel passing back over or close to its geographic point of origin after several days within the moving high.

The northeastern quadrant of an anticyclone is generally characterized by northwesterly flow and is the region that exhibits post-cold-frontal conditions. Generally low levels of pollutants are found in this area because of rainout and the deep mixing associated with frontal zones. The air mass behind the front is generally cool, dry Canadian air, comparatively free of pollutants. Shenfeld (1977) has shown relatively low concentrations of oxidants to exist in the forest lands of Canada where these post cold frontal air masses originate. As the air moves southward, it is modified through heat and moisture flux at the surface. Furthermore, the concentration of primary air pollutants increases due to emissions from isolated point sources, cities, and towns. Chemical and photochemical reactions take place, and some primary pollutants are gradually transformed, creating secondary pollutants within the air mass. The photochemical reactions are enhanced in the relatively cloudfree environment of the high, and limited vertical mixing allows pollutant concentrations to accumulate in the boundary layer.

The data presented for the 16 June–31 August 1974, study period appear to support this primary–secondary pollutant interrelationship. Also during periods when high pressure systems dominate, restricted visibility appears to be a reasonable surrogate measure-

ment of the relative concentrations of secondary pollutants, particularly sulfate and ozone. The four case studies support the hypothesis that peak pollution levels within a transient anticyclone are directly related to air parcel residence time.

REFERENCES

Bach W. D., King W. J. and Vukovich F. M. (1976) Nonurban ozone concentrations in transient high pressure systems. Presented at the Symposium on the Non-Urban Troposphere, Hollywood, Florida, 14 November.

Decker C. E., Ripperton L. A., Worth J. J. B., Vukovich F. M., Bach W. D., Tommerdahl J. B., Smith F. and Wagoner D. E. (1976) Formation and transport of oxidants along the Gulf coast and in the Northern United States. Environmental Protection Agency, Report No. EPA-450/3-76-033, Research Triangle Park, NC.

Environmental Protection Agency (1974) Investigation of ozone and ozone precursor concentrations at non-urban locations in the Eastern United States. Report No. EPA-450/3-74-034, Research Triangle Park, NC.

Environmental Protection Agency (1975) Investigation of rural oxidant levels as related to urban hydrocarbon control strategies. Report No. EPA-450/3-75-036, Research Triangle Park, NC.

Husar R. B., Patterson D. E., Paley C. C. and Gillani N. V. (1976) Ozone in Hazy Air Masses. *Proc. Int. Conf. on Photochem. Oxidant Pollut. and its Control.* EPA-600/3-77-001A, Research Triangle Park, NC, pp. 275–282.

Sampson P. and Ragland K. (1977) Ozone and visibility reduction in the midwest: evidence of large-scale transport. *J. appl. Met.* **16**, 1101–1106.

Shenfeld L. (1976) Report on oxidants and their precursors in Canada. *Proc. Int. Conf. Photochem. Oxidant Pollut. and its Control.* EPA-600/3-77-001A, Research Triangle Park, NC, pp. 917–927.

Spicer C. W., Joseph D. W., Sticksel P. R. and Ward G. F. (1979) Ozone sources and transport in the Northeastern United States. *Envir. Sci. Technol.* **13**, 975–985.

Vukovich F. M., Bach W. D., Crissman B. W. and King W. J. (1977) On the relationship between high ozone in the rural surface layer and high pressure systems. *Atmospheric Environment* **11**, 967–983.

Vukovich F. M. (1979) A note on air quality in high pressure systems. *Atmospheric Environment* **13**, 255–265.

Wolff G. T., Lioy P. J., Wight G. D., Meyers R. E. and Cederwall R. T. (1976) An investigation of long-range transport of ozone across the Midwestern and Eastern United States. *Proc. Int. Conf. Photochem. Oxidant Pollut. and Its Control.* EPA-600/3-77-001A, Research Triangle Park, NC, 307–318.

Wolff G. T., Kelly N. A. and Ferman M. A. (1981) On the sources of summertime haze in the Eastern United States. *Science* **211**, 703–705.